



LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Pushing the limits of plasma length scaling in inertial fusion laser-plasma interaction experiments

D. Froula, L. Divol, R. London, P. Michel, R. L. Berger,
N. B. Meezan, P. Neumayer, J. S. Ross, R. Wallace, L.
Suter, S. H. Glenzer

August 22, 2007

37th Anomalous Absorption Conference
Kaanapali Beach, HI, United States
August 27, 2007 through August 31, 2007

Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

Pushing the limits of plasma length in inertial fusion laser-plasma interaction experiments

**Presentation to
Anomalous Absorption Conference**

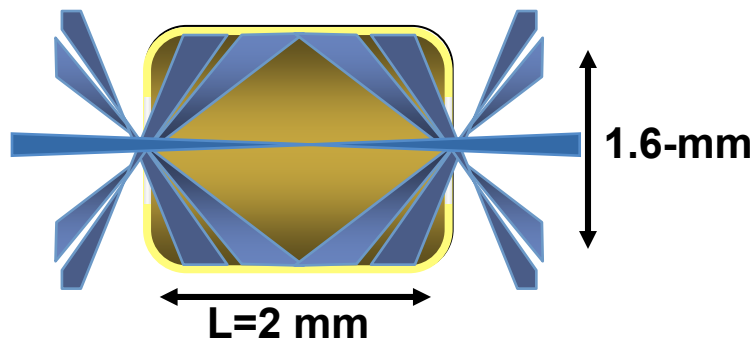


D. H. Froula

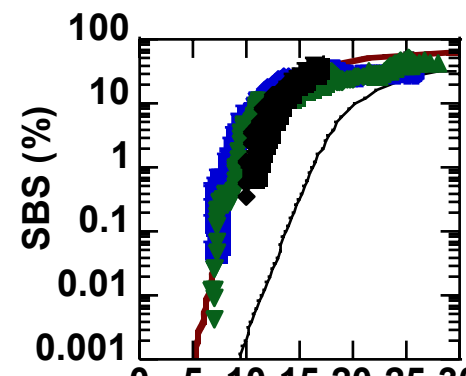
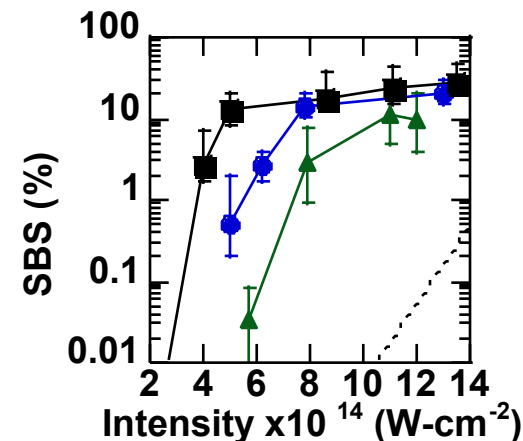
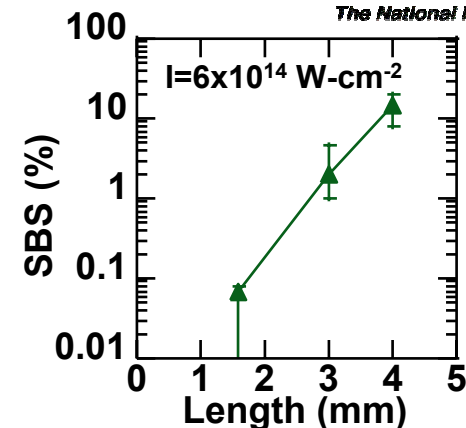
**L. Divol, R. London, P. Michel, R. Berger, N. B. Meezan,
P. Neumayer, J. S. Ross, R. Wallace, L. Suter, and S. H. Glenzer**

August 2007

Outline



- The backscatter is measured to increase exponentially with length (2 mm \rightarrow 5 mm)
- The SBS threshold ($R \sim 5\%$) is doubled when the length is reduced by a factor of 2 as expected by linear theory
- Results compare well with recently implemented 3D LPI code (SLIP)
 - See P. Michel's Poster
- Experimental results scale with linear gain providing confidence in our ability to design ignition targets



The interaction beam propagates along the hohlraum axis interacting with a high-temperature uniform plasma

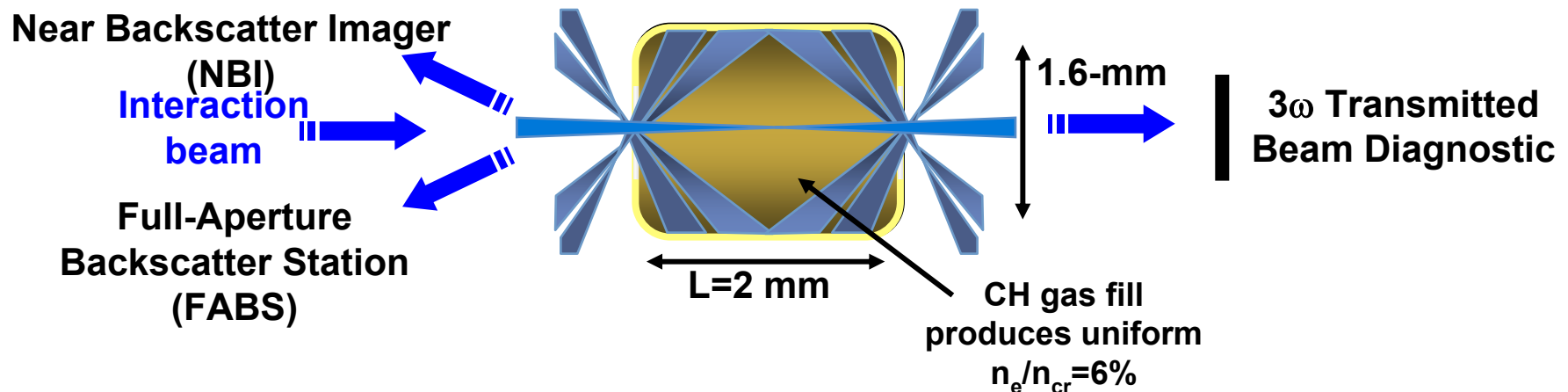
Our motivation for this series of Omega LPI experiments is to test linear theory as a metric for determining the on-set of backscatter

Omega experiments are studying the scaling of backscatter with:

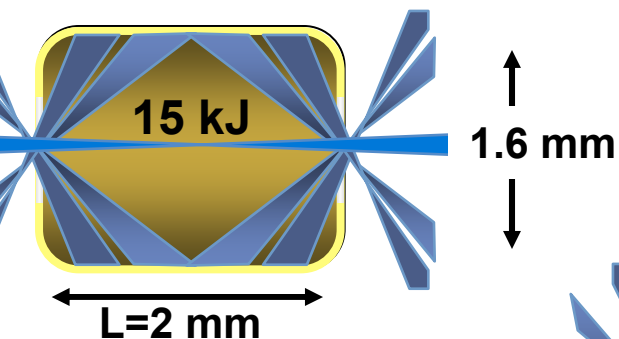
- **Electron temperature** [Phys. Rev. Lett. 98, 085001 (2007)]
- **Intensity** [Phys. Plasmas 14, 055705 (2007)]
- **Landau damping** (ω_a/v_a) [P. Neumayer, Poster Session]
- **Plasma Length (2-mm, 3.5-mm, 5-mm)** [This Talk]

$$G \propto \frac{n_e}{T_e v_a} \int_{-L/2}^{L/2} I dz$$

In addition, these experiments have been used to benchmark 3D laser-plasma interaction simulations



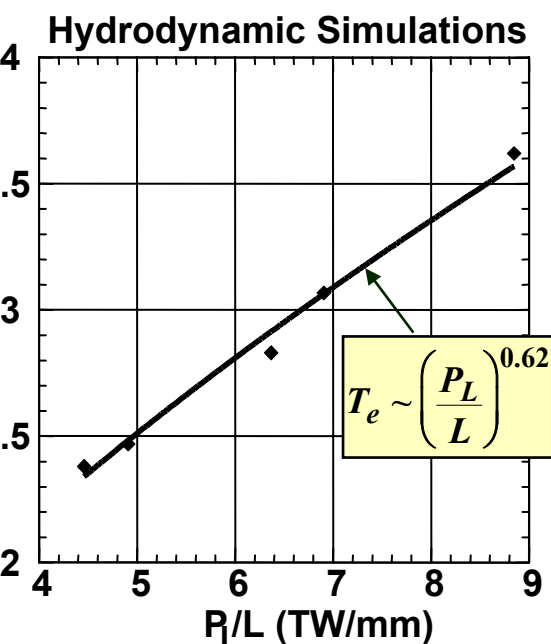
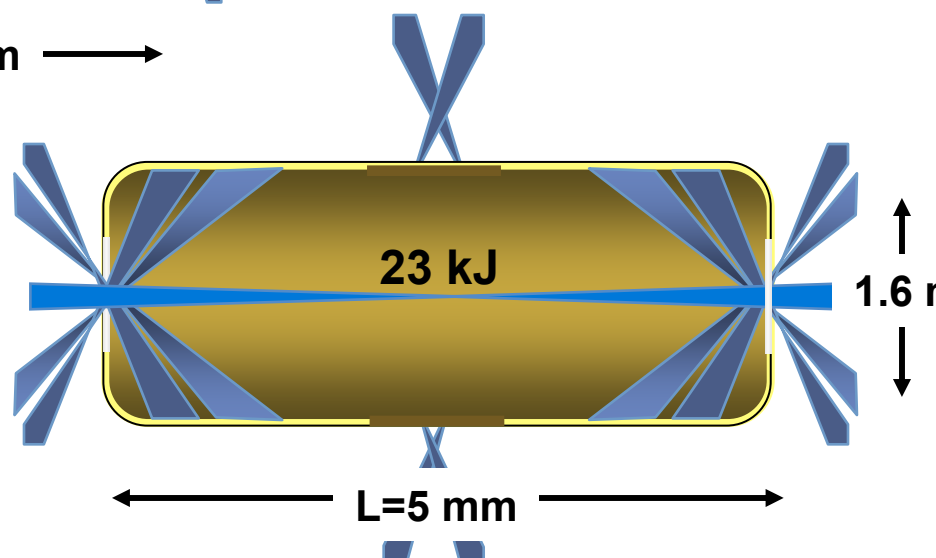
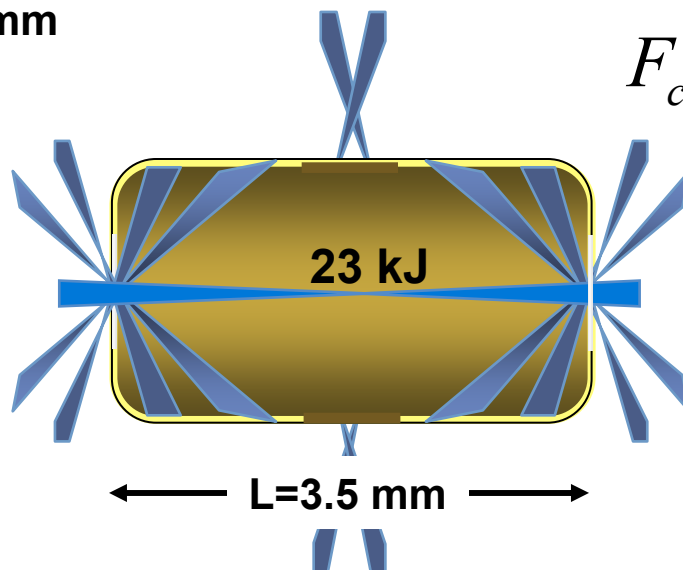
The interaction length was scaled to 5 mm while maintaining the peak electron temperature above 2.5 keV



Equate absorbed laser power to conductive loss from hot CH+Au into cold Au wall:

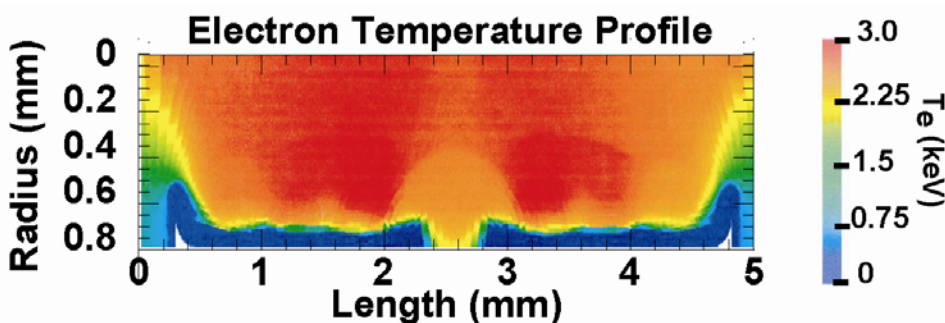
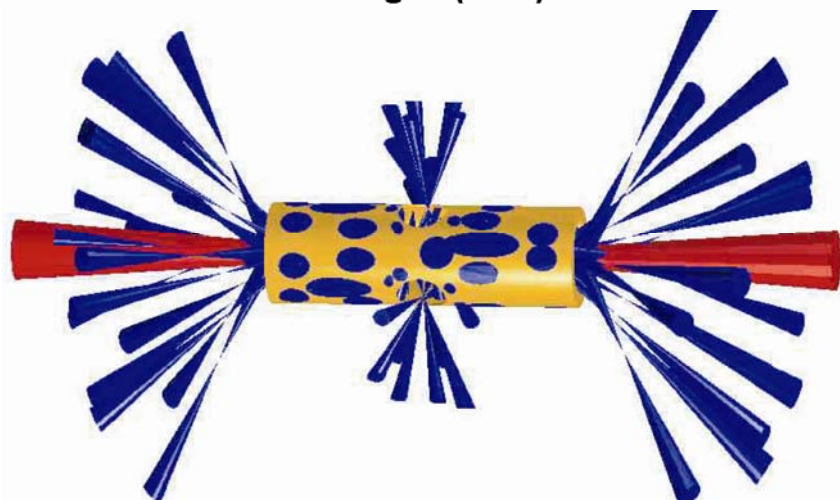
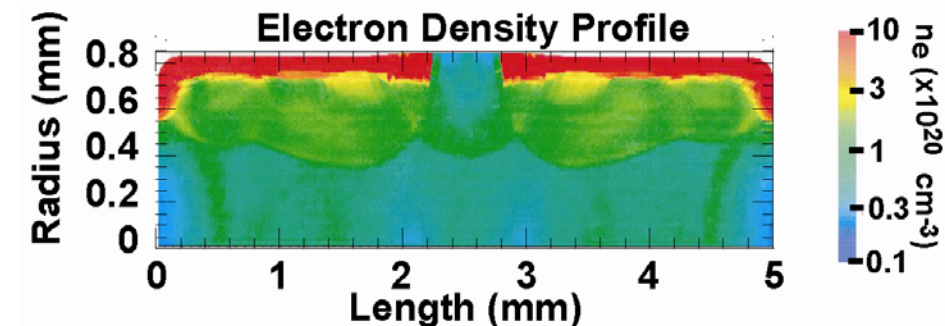
$$F_c = f n_e v_{e,th} T_e \sim f n_e T_e^{3/2}$$

$$\Rightarrow T_e \sim (n_e f_c r)^{-2/3} \left(\frac{P_L}{L} \right)^{2/3}$$

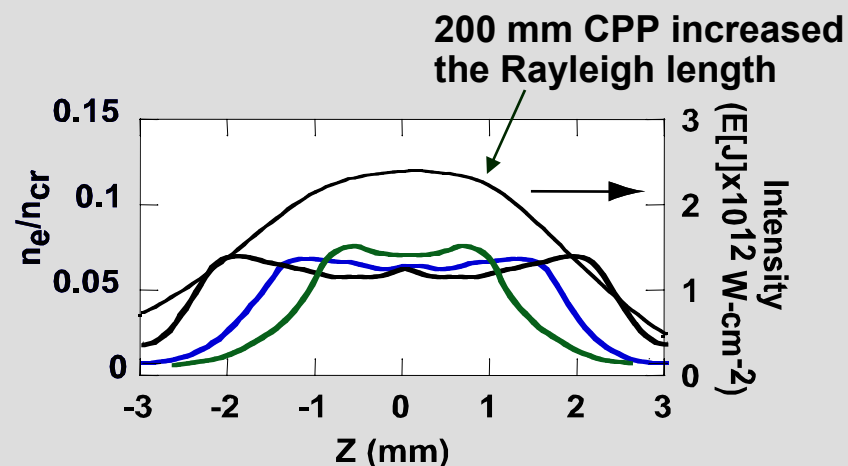


Adding 17 heater beams along the equator provided the laser power to keep the electron temperature above 2.5 keV for the 5 mm target

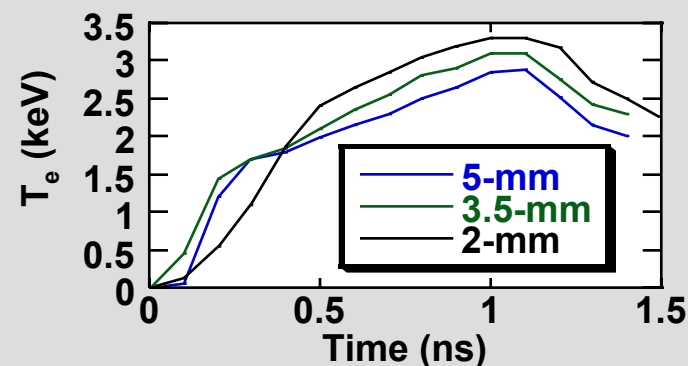
In all three targets, the interaction beam propagates through high temperature ($T_e > 2.5$ keV) plasmas in a uniform 6% N_{cr} density



The intensity profile and density plateau is shown along the interaction beam path

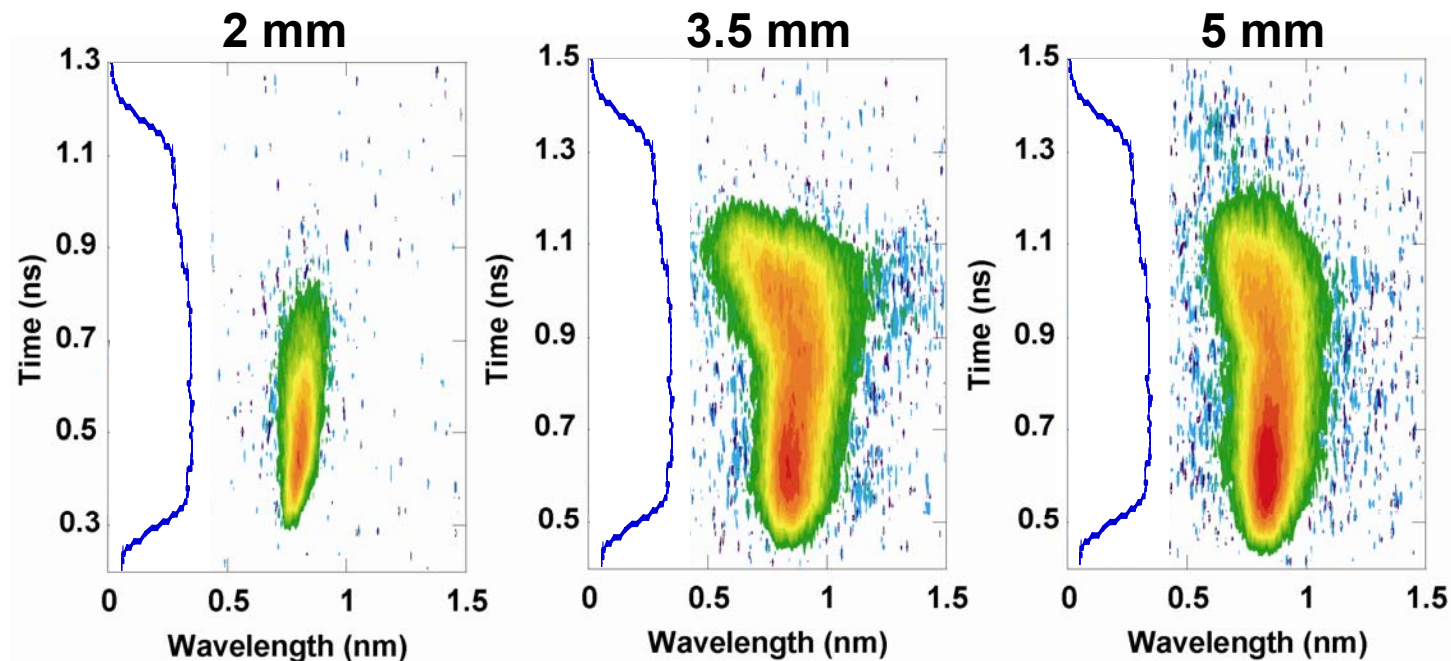


The electron temperature exceeds 2.5 keV in all three target platforms



SBS spectra show uniform high temperature plasma conditions

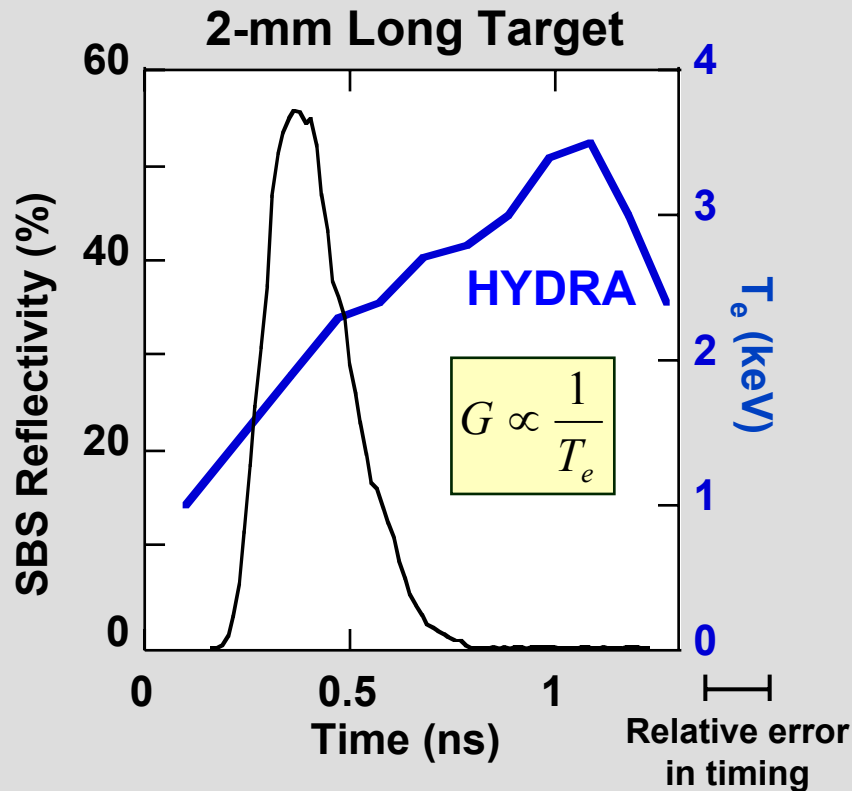
- The SBS spectra are narrow and shifted by $\Delta\lambda > 0.8$ nm corresponding to a $T_e > 2.5$ keV
- Broadened spectrum in the 3.5-mm and 5-mm results is a result of larger ion temperature



$$I = 1.2 \times 10^{15} \text{ W-cm}^{-2}$$

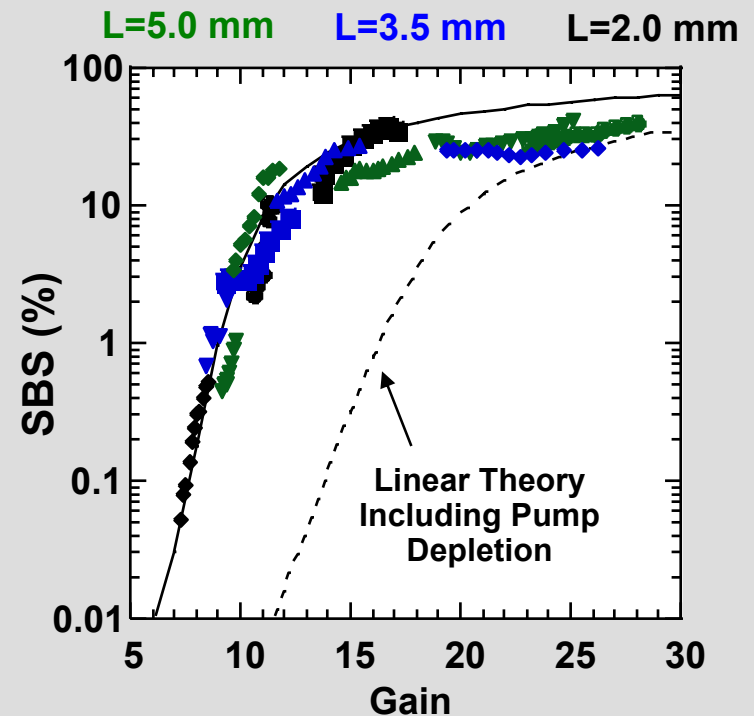
Backscatter scales exponentially with length, increasing three orders of magnitude when increasing the length by a factor of 2

The SBS reflectivity and **electron temperature** as a function of time is shown



SBS is less than 1% for T_e above 3 keV in the 2 mm long targets

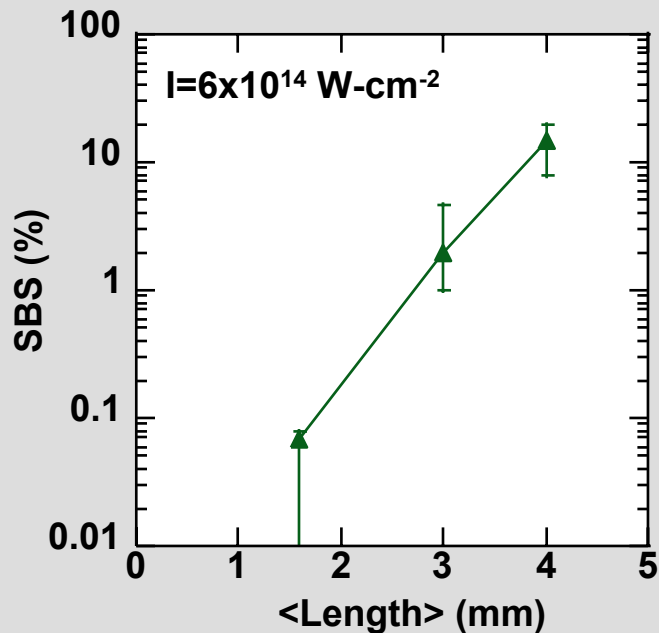
The SBS reflectivity is shown for the 2-mm, 3.5-mm, and 5-mm long targets



SBS reflectivity scales with the linear gain calculated by LIP

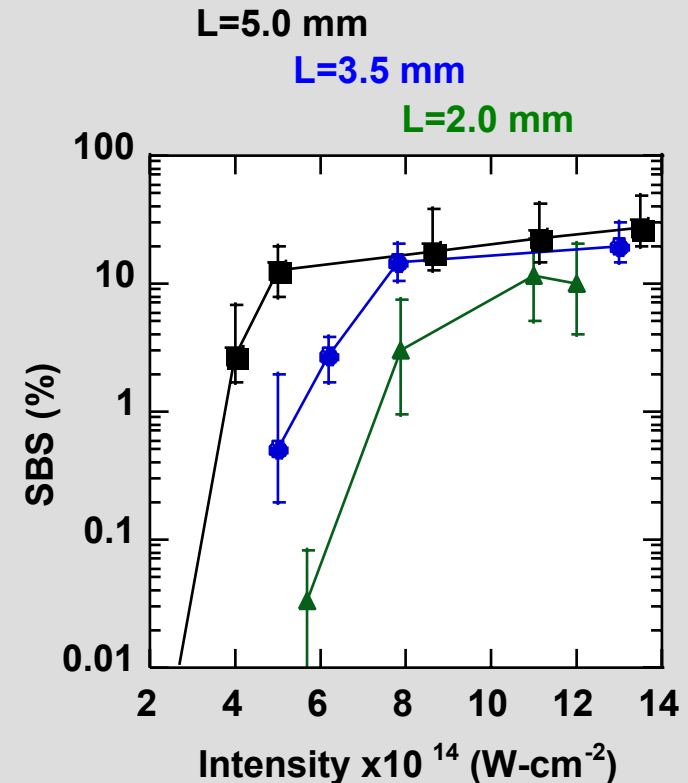
The SBS reflectivity is measured to increase exponentially with intensity and length

The instantaneous ($t=700$ ps) SBS reflectivity is measured as a function of length



$$\langle L \rangle_I = \frac{\int_{-L/2}^{+L/2} I(z) dz}{I_{\max}}$$

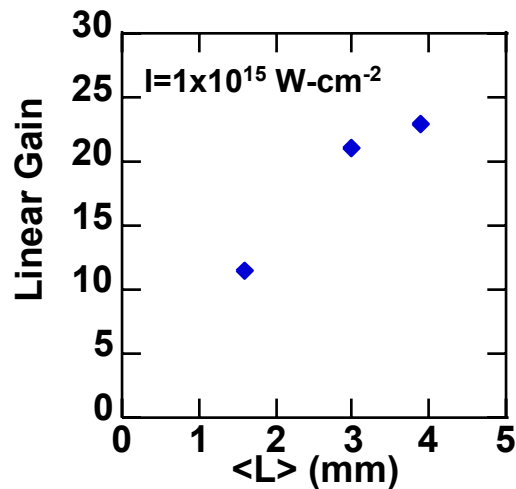
The SBS reflectivity is shown for the 2-mm, 3.5-mm, and 5-mm long targets



The SBS reflectivity increases to saturation for all three target lengths

The SBS threshold ($R \sim 5\%$) is doubled when the length is reduced by a factor of ~ 2

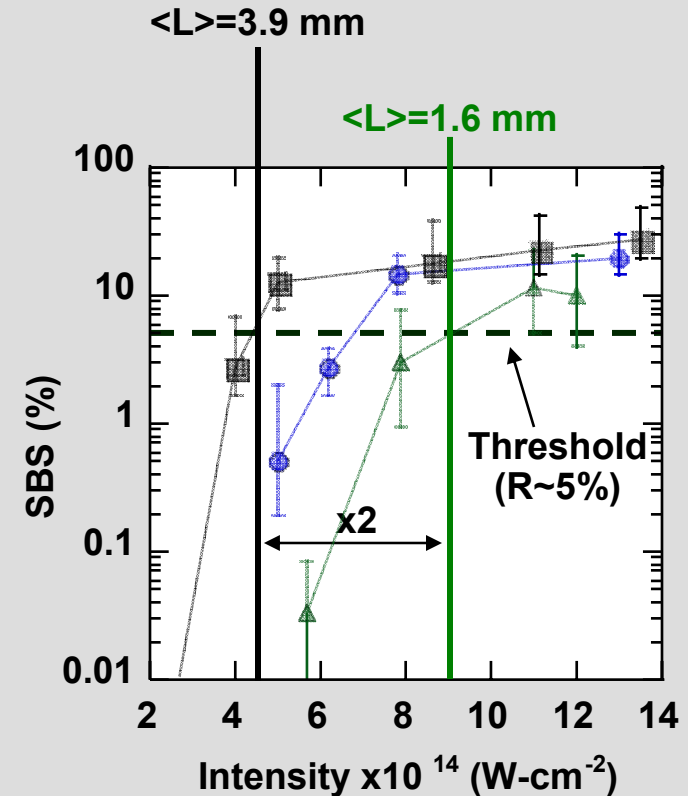
- $G \propto \int_{-L/2}^{L/2} I(z) dz$



- $\frac{L_{3.5\text{mm}}}{L_{2\text{mm}}} = 1.87 \Rightarrow \frac{G_{3.5\text{mm}}}{G_{2\text{mm}}} = 1.85$

- $\frac{L_{5\text{mm}}}{L_{2\text{mm}}} = 2.4 \Rightarrow \frac{G_{5\text{mm}}}{G_{2\text{mm}}} = 2.0$

The SBS reflectivity is shown for the 2-mm, 3.5-mm, and 5-mm long targets



The SBS threshold ($R \sim 5\%$) is doubled when the length is reduced by a factor of 2

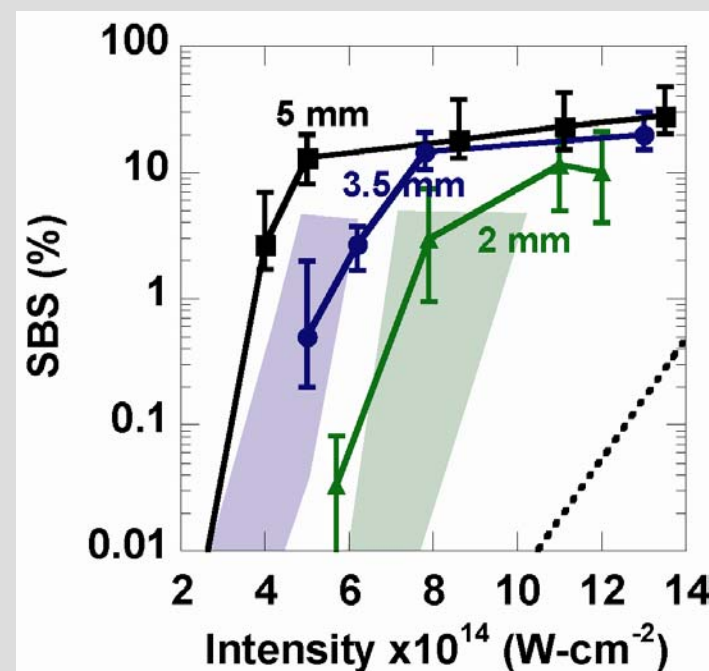
Consistent with linear gain

3D nature of the laser beam is required to calculate the measured SBS thresholds

- SLIP: New 3D steady state wave solver
 - P. Michel, Poster Session
- SLIP includes 3D nature of the laser beam (e.g. speckles)
 - LIP uses an average intensity
- Near threshold, SLIP shows contribution to SBS from the most intense speckles
 - Ave. intensity still below threshold (LIP)
- Backscatter power from these speckles is low, but amplifies the thermal noise which triggers SBS for the whole beam

The SBS reflectivity calculated by SLIP for the 2-mm, 3.5-mm, and 5-mm long targets

$\langle L \rangle = 1.6$ mm
 $\langle L \rangle = 3$ mm $\langle L \rangle = 3.9$ mm



SLIP calculations are consistent with the SBS threshold for the 2-mm and 3.5-mm targets

We have demonstrated that SBS scales with plasma-length as predicted by linear theory for high temperature fusion conditions

- The backscatter is measured to increase exponentially with length—increasing by several orders of magnitude when $L=1.6 \rightarrow 3.9$ mm
- The SBS threshold ($R \sim 5\%$) is doubled ($I_{5\text{-mm}} = 6 \times 10^{14} \text{ W-cm}^{-2} \rightarrow I_{2\text{-mm}} = 13 \times 10^{14} \text{ W-cm}^{-2}$) when the length is reduced by a factor of 2
- Results compare well with recently implemented 3D LPI code (SLIP)
— See P. Michel's Poster
- Experimental results scale with linear gain providing confidence in our ability to design ignition targets

